Outline

• Requirements and drivers for tank bottom inspection
  ➢ Regulatory Requirements, API 653, company practices
  ➢ Incentives of on-stream inspection

• Potential degradation mechanisms for tank floor bottoms
  ➢ General Bottom
  ➢ Annular Ring/Critical Zone

• Existing approaches and technologies for on-stream bottom inspection
  ➢ Approach: RBI (Risk Based Inspection)
  ➢ Technologies to support data driven approach
    • AE (Acoustic Emission)
    • Tank robotics
    • Ultrasonic techniques
    • Technology gaps

• Summary and Conclusions
Tank Bottom Inspection Drivers

- Numerous reasons/drivers for tank inspection (e.g., bottom, shell, roof, seals)

- Most inspection standards/requirements (e.g., API 653 and regulatory requirements) are primarily focused on mechanical integrity for the purpose of addressing loss management and Safety/Health/Environmental concerns

- Maintaining a tank with proper mechanical integrity is consistent with inspection standards, regulatory requirements, and equipment availability.

- Among the primary tank mechanical integrity components, tank bottoms are one of the most difficult area to inspect on-stream (while the tank is in-service)
Tank Bottom Inspection—Onstream Incentives

• Tank bottoms may be readily inspected while the tank is down (out-of-service) and this is often the basis for taking a tank out of service (for internal inspection)

• While an out-of-service inspection may appear to be the “right” solution for any (and every) tank bottom assessment, there are many incentives for an on-stream bottom assessment, including:
  ➢ Tanks entered for inspection may need to be drained, cleaned, and have an internal atmosphere control procedure applied.
  ➢ Tank entry and cleaning involves the handling and proper management/disposal of waste/sludge.
  ➢ Identification and assessment of unexpected degradation mechanisms or accelerated corrosion rates that may be identified through a condition based RBI program.
    • On-stream inspection may address potential concerns for operational or bottom side condition changes that may affect bottom integrity (e.g., potential problem with sump, MIC-Microbial Induced Corrosion, cathodic protection, water table level, etc.).
  ➢ Planning for maintenance work
    • On-stream bottom assessment can play a beneficial role in planning (e.g., outage time, material, and man power resources) prior to entry
  ➢ Many tanks are operated in locations where Risk Based Inspection is allowed.
    • Reliable NDE methods are necessary to support RBI, otherwise the potential variability on probability of failure can be quite significant (and be overly or under conservative). The inclusion of reliable on-stream NDE methods enhances RBI methodology by improving estimate of appropriate out-of-service date.
Tank Bottom Degradation—General

- General bottom corrosion may be considered as the entire floor, except for the critical zone.

- Bottom area is substantial (tanks may be 30m, 60m, or even 90 m in diameter).

- Corrosion is often randomly distributed, uniform corrosion or pitting (especially for bottom side corrosion):
  - “left over” welding rods or inadvertent fill problems (e.g., clay ball or stone) do not fall under this category.
  - Product side of floors may be coated and future coating failures may be isolated.
  - Localized product side corrosion may occur at low points (e.g., sumps).
Annular Ring/Critical Zone

- Critical zone is defined by API 653 as “…portion of the tank bottom or annular plate within 3 in. (75 mm) of the inside edge of the shell, measured radially inward…”

- Failure in this area may result in a leak as well, however, the potential for a rupture here is greater (compared to the general bottom area)
<table>
<thead>
<tr>
<th>Potential Forms of Corrosion/Degradation in Critical Zone</th>
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<tbody>
<tr>
<td><strong>Classically Bottom Side “groove” corrosion</strong></td>
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<tr>
<td><img src="image" alt="Diagram showing classic bottom side corrosion" /></td>
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<tr>
<td><strong>Soil Side Corrosion—Distal</strong></td>
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<td><img src="image" alt="Diagram showing soil side corrosion—distal" /></td>
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<tr>
<td><strong>Soil Side Corrosion—General Knife Edge</strong></td>
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<tr>
<td><img src="image" alt="Diagram showing soil side corrosion—general knife edge" /></td>
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<tr>
<td><strong>Gutter Corrosion</strong></td>
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<td><img src="image" alt="Diagram showing gutter corrosion" /></td>
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Tank Annular Ring “Groove” Corrosion

- **Issue:** Localized “groove” corrosion (typically bottom side, though product side is possible) may occur at annular ring area of above ground storage tanks. The bottom side corrosion is less common in non-heated tanks.

- **Identification of this corrosion can be very difficult during internal inspection due to corrosion location (bottom side and near shell-floor joint) and on-stream technology has been progressing slowly.**
  - Floor scanners cannot inspect at toe of inner fillet weld
  - Traditional UT measurements have limited ability at weld toe due to access
  - Significant amount of corrosion may actually be under inner fillet weld and this may be difficult to detect.
Corrosion of Critical Zone May be Highly Localized

• Field experience has demonstrated that affected area may be limited to 2m out of 200m circumference (balance of tank had <1 mm loss).
  ➢ API 653 or API 579 (Fitness for Service) may be used to assess condition

• Other tanks have shown this corrosion can be intermittent/isolated

• Heated tanks tend to have a more consistent corrosion pattern, however, it is not always consistent and this corrosion problem can occur on non-heated tanks.

Affected Circumferential Length of Tank Bottom May be as Small as 1%

Where to look?
Status of Tank Annular Ring Corrosion Inspection

- API 653 and API 581 do have some language to address this potential item
  - API 653: 4.4.3.1 Internal Inspection: “Internal inspection of the tank bottom is intended to assess the current bottom integrity and identify problem conditions that may lead to future loss of integrity.”
  - API 581: Table 5.10 requires “Hand scan of critical zone”, however, this is only required for “Highly Effective” inspection

- The need and approach for an effective annular ring inspection may not be well recognized throughout industry.
  - Root cause failure analysis of prior leaks and tank bottom inspection reports
    - Prior inspection in this area may not have been performed if a full floor replacement was done. However, potential for this mechanism should be considered for operators considering extension of inspection intervals (e.g., for remediation through coating/lining of bottoms)

- Potential areas for improvement
  - Re-evaluate practices/systems to address annular ring issue (e.g., failure probability guidance, inspection guidance, etc.)
  - Development and assessment of new on-stream inspection technologies to identify and assess annular ring corrosion.
Onstream Inspection Approach--RBI

- Risk Based Inspection (RBI) addresses both the consequence and probability of a potential scenario.

- Generally speaking, a robust RBI program will provide a reliable approach to achieve equipment integrity.
  - A robust RBI system inherently drives the operator to identify credible degradation mechanisms and address them appropriately (and within the context of other risks).
  - Calendar based inspections are inherently less targeted, though they generally require less “analysis” and rigor in planning.
    - They may result in intervals that are sub optimal (too short or too long) since they are by design “generic”.
    - They may ultimately provide less reliability than a robust RBI program and divert valuable resources.
On-stream Inspection
Approach/Technologies

- Determining Probability of Failure (PoF) is focus of this presentation.
  - Consequence assessments are typically developed and defined by the Owner/User.

- “Paper” based PoF
  - Future PoF may be estimated based on prior inspection data (e.g., prior out-of-service inspection)
  - Challenges associated with estimating PoF: Availability of inspection data, age of data, quality of data (e.g., equipment and operator performance).
  - Experience based (e.g., age) and environment based (e.g., product, coating, cathodic protection, foundation type, etc.)
    - Challenge: How to validate assumptions (essentially based on “similar service”)?

- Field inspection technologies are available and may be used to augment the “paper based” estimate of PoF and thereby improve the estimated PoF for the tank bottom.
  - General Bottom
  - Critical Zone
On-stream Inspection Technologies

- **General Bottom Corrosion**
  - Acoustic Emission
  - In-service tank robotics

- **Critical Zone Corrosion**
  - Excavation
  - PEC (Pulsed Eddy Current)
  - Angle beam UT (Ultrasonic Testing)
  - “short” range guided wave
Acoustic Emission

• Objectives of inspection
  ➢ Refine “paper” Probability of Failure estimate based on tank AE test results.
  ➢ May also consider for leak detection and tank maintenance prioritization

• Capabilities, Limitations, and References
  ➢ AE monitors tank floor “activity” to help identify localized corrosion areas and relative activity of floor (compared to other tanks).
  ➢ AE does not provide direct floor thickness measurement or corrosion rate.
  ➢ Significant amount of empirical work done in 1990’s (Van De Loo, P.J.) and 2000’s (Shigenori Yuyama, et. al.)

• Application and Techniques
  ➢ Generally requires the tank to be isolated (valves or blinding) for 24 hours and monitored with acoustic emission monitoring sensors
  ➢ Techniques and interpretation of results may vary among vendors
  ➢ One technique/approach is Mistras’ TankPAC™ approach with an A-E grading system

  A – Very Minor/No Damage  
  B – Minor Damage  
  C – Intermediate Damage  
  D – Active Damage  
  E – Highly Active Damage
Acoustic Emission Example Results

A-grade AET results with very minor activity.

D-grade AET results with significant activity corrosion verified throughout floor and especially along floor to shell area.

A – Very Minor/No Damage
B – Minor Damage
C – Intermediate Damage
D – Active Damage
E – Highly Active Damage
AE Application Considerations

- Integration into RBI program
  - Translation of AE results into a refined PoF estimate
  - How long are the results “valid” and applicable?

- Cautions and Other Application Considerations
  - Background Noise (e.g., leaking valves, rain, wind, etc.)
  - Qualified Operators
  - Climate/active corrosion

“B” Tank Example
Tank tested after drought and given B-grade. Validation showed no perforation, but, significant areas of soil side corrosion, though soil was very dry at time of test and out-of-service inspection.
Onstream Robotic Inspection

• Objective of inspection
  ➢ Gather high quantity of tank floor thickness measurements to determine current floor condition (estimation of deepest pit) for evaluation of soil-side or product-side corrosion
  ➢ Use calculated MRT (min. req’ed thickness) to assist in scheduling of next steps (e.g., leak test and in-service inspection, or, tank entry)

• Capabilities and Limitations
  ➢ Can be used for in-service inspections eliminating the need for tank entry and cleaning (cost varies among providers and location)
  ➢ Numerous thickness readings gathered allow application of Extreme Value Analysis (EVA) to estimate deepest pit
  ➢ Can also be used to gauge tank settlement and perform inspection of floating roof seals
  ➢ Depth of sludge can limit capability to maneuver inside the tank increasing inspection time or making inspection impractical
  ➢ Limited capability to gather information near the outside of the tank in the annular ring area
  ➢ EVA not suitable for predicting a single isolated pit from a point source beneath the tank (method assumes corrosion is randomly distributed)
Critical Zone Inspection: Challenges

• Design of annular ring/chime area
• Access to chime area
• Condition of chime area
• Size of available chime area
• Shape, location, and extent of corrosion

General Corrosion

Localized Corrosion
Critical Zone Inspection: Options/Considerations/Needs

- **Excavation:** May be applicable as a complementary method, but, not as a primary one.
  - Corrosion can be very isolated
  - Tank may be built upon concrete ring wall or foundation
  - Inherent risk associated with removing foundation/support at area with unknown significant corrosion

- **INCOTest/PEC**
  - Similar concerns as with excavation, however, useful in collecting thickness measurements
Angle Beam and Short Range UT: Methods

- Numerous ultrasonic techniques have been developed and utilized to address the inspection of annular rings.
  - Many have used a shear wave multiple skip approach
  - Some have considered short range guided wave technology
  - Most have been piezoelectric transducers, at least one has used a magnetostrictive approach
Angle Beam and Short Range UT: Experience

- Experience
  - Initially, most techniques had difficulty looking in critical zone area. Emphasis was on general bottom condition up to 1m past shell to floor joint.
  - Many have demonstrated ability to detect groove type damage.

Example of on-stream annular ring inspection results:

Area of interest (critical zone area) with relative severity of “< 50 %” linear Indication.
Angle Beam and Short Range UT: Limitations and Gaps

• Technology needs/limitations
  - Vast majority of methods are amplitude based and therefore, many variables will affect estimated size of indication.
    - Condition and thickness of chime area (outer lip)
    - Shape of corrosion groove (cross sectional profile)
    - Length of corrosion (minor issue)
  - Need to establish proper estimate of POD (probability of detection) based on groove depth
  - Need to establish sizing capability
Summary and Conclusions

- Risk Based Inspection of tank floor bottoms can provide a robust and reliable approach to tank mechanical integrity programs
- On-stream inspection is a valuable component of tank floor RBI
- Operators need to consider and address the various forms of tank bottom degradation (e.g., general floor corrosion, critical zone-4 types)
- On-stream inspection technology options are currently available to support tank floor assessment
- Opportunities exist to help close technology gaps and thereby enhance tank bottom RBI programs